

VLA IMAGING OF PROTOPLANETARY ENVIRONMENTS

Grant NAG5-8195

Annual Report

For the period 1 February 2002 through 31 January 2003

Principal Investigator

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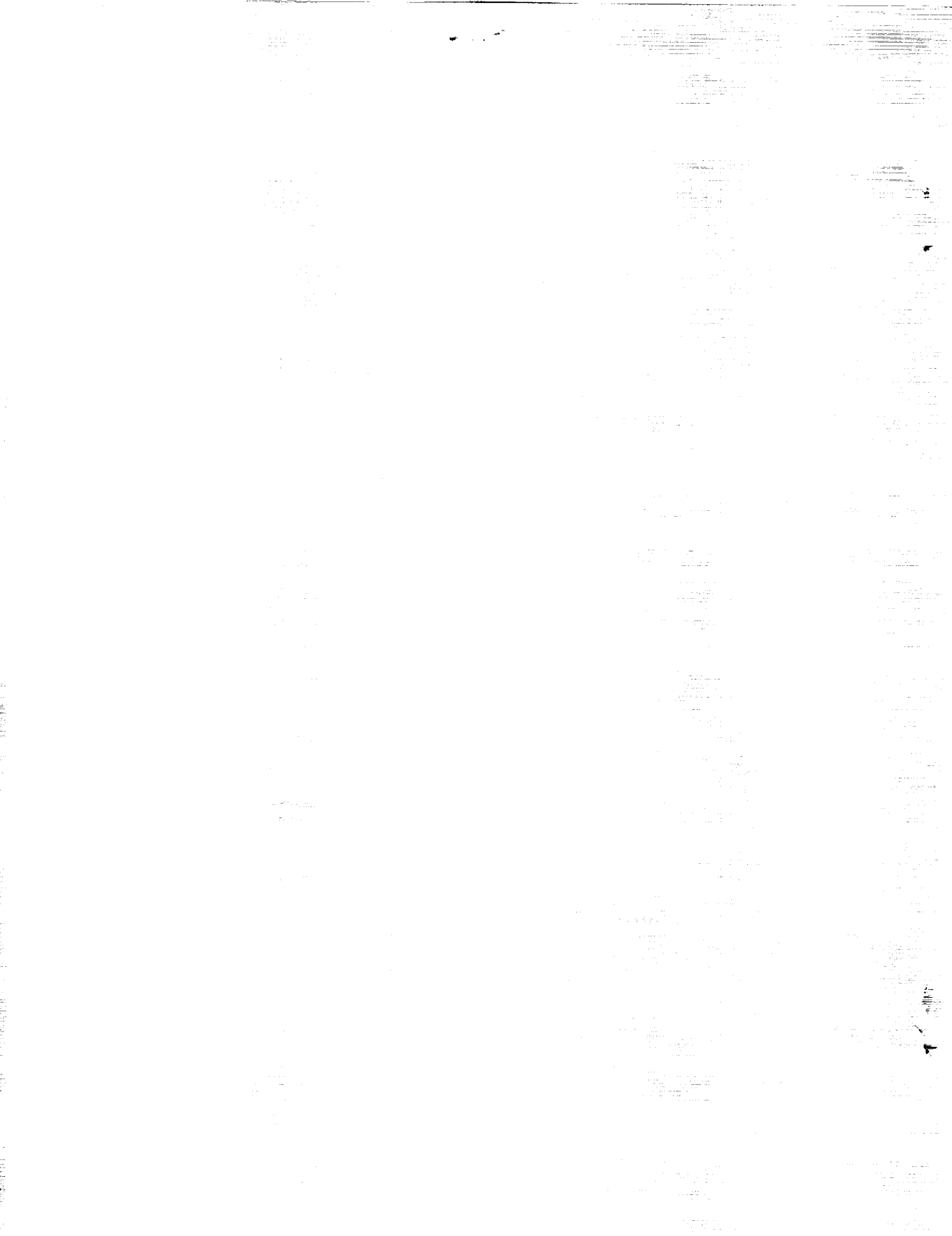
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Our program uses the techniques of millimeter interferometry to make high resolution observations of dust continuum emission to study the structure of protoplanetary disks around nearby stars. We continue to use the Very Large Array (VLA) of the National Radio Astronomy Observatories (NRAO) to make produce high angular resolution images, and we are improving our capabilities to interpret these observations with detailed numerical models. We have also made the first millimeter interferometer observations of protoplanetary disks in the southern hemisphere, using the recently upgraded Australia Telescope Compact Array (ATCA), taking advantage of the techniques we have developed in our work on northern sources.

We describe accomplishments of the past year and plans for next year:

1. We completed analysis of the VLA observations of the disk surrounding the 10 Myr old 1.5 solar mass pre-main-sequence star CQ Tauri. Much of the effort involved improving the disk models, which are similar to the two-layer model of Chiang and Goldreich (1997), with a more accurate scheme to compute disk flaring and more realistic dust prescriptions for the disk midplane and surface.

The subarcsecond 7 millimeter observations of CQ Tauri clearly resolve the disk (see Figure 1). We interpret the observed fluxes from 7 to 1.3 millimeters together with the resolved 7 millimeter structure. We find that the disk radius is constrained to the range 100 to 300 AU, depending on the steepness of the disk surface density distribution, which is likely close to r^{-1} , and that the power law index of the dust opacity coefficient, β , is constrained to be 0.5 to 0.7. Since the models indicate that the disk is optically thin at millimeter wavelengths for radii greater than 8 AU, the contribution of an optically thick region to the emission is less than 10%. This implies that high optical depth or complex disk geometry cannot be the cause of the observed shallow millimeter spectral index. Instead, the new analysis supports the earlier suggestion that dust particles in the disk have grown to sizes as large as a few centimeters. The dust in the CQ Tauri system appears to be evolved much like that in the TW Hydra system (Wilner et al. 2000).

2. Using the newly upgraded ATCA, we have made the first millimeter interferometer observations of protoplanetary disks in the southern hemisphere, where there are

many very interesting sources that are difficult or impossible to observe with the VLA. Our preliminary observations at 3.4 millimeters using only three antennas are very encouraging. We detected compact thermal dust continuum emission from both targets, the disks surrounding TW Hydra and HD 100546. For TW Hydra, we also detected and resolved HCO^+ $J=1-0$ line emission from the disk, with properties in good agreement with model calculations of irradiated accretion disks with substantial molecular depletions. A paper on this work is expected to be submitted in January 2003.

3. We have been awarded time for additional “low resolution” 7 millimeter observations of disks around T Tauri stars, a few more massive Herbig Ae stars, as well as a few disks in binary systems, to be made in early 2003 when the VLA is in the compact D configuration. Some of these observations repeat those made in the earliest days of this grant, now that the VLA 7 millimeter system is more mature and much more sensitive. In addition, we expect systematic uncertainties in the absolute flux scale will be substantially less, which will better define the long wavelength spectra and help in the understanding of grain size evolution. These observations will provide good total flux measurements and will identify new candidates for high resolution follow-up.
4. We continue make progress modeling our high resolution VLA 7 millimeter observations, using improved computational machinery as shown in the CQ Tauri work. Our goal is to complete and publish a full analysis of the resolved millimeter data on selected disk systems, considering implications for accretion physics, grain growth, and initial conditions for planet formation.

References

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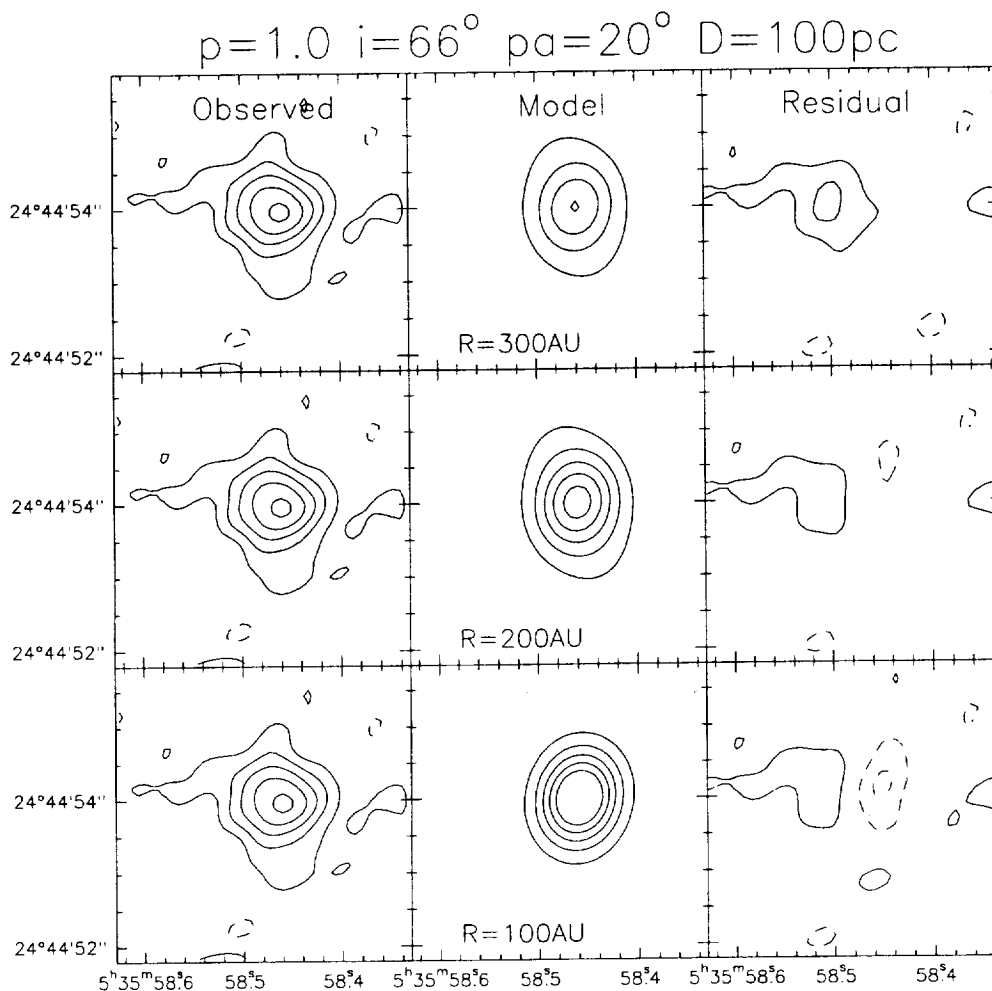


Fig. 1.— Comparison between observed and synthetic 7 millimeter images of the CQ Tau protoplanetary disk. The observed image is shown in the left panels, with contour levels that start at 2σ and are spaced by 2σ ($1\sigma = 0.1$ mJy). The synthetic models in the central panels show three different values of the disk radius; the surface density power law index ($p=1.0$), inclination ($i=66$ degrees) and position angle (20 degrees) are the same for all models shown, using the same contours. On the right panels are the residuals after subtraction of the model. All of these models reproduce the integrated fluxes at 1.3, 3, and 7 millimeters. The best fit value of the power law index of the dust opacity coefficient, β , ranges from 0.55 for disks with $p=0.5$, to 0.6 for $p=1$, to 0.7 for $p=1.5$. In all of the models, the contribution of the inner optically thick disk is less than 10%. Thus the models, together with the flux constraints, confirm that the millimeter emission originates from an optically thin disk with a population of large grains, a clear indication of grain growth.

